

# Warm Absorbers in Active Galactic Nuclei

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## Abstract

Observations of warm absorbers provided new ways to study the nuclear environments of AGNs. I discuss basic properties of warm absorbers and early developments with ROSAT, ASCA and HST observations. I briefly touch upon recent advances made with *Chandra* and FUSE.

*Key-words* : quasars: absorption lines– ultraviolet: galaxies– X-rays: galaxies

## 1 Introduction: Warm absorbers with ROSAT and ASCA

What is a X-ray warm absorber? ROSAT observations of some Seyfert galaxies showed that a simple power-law does not describe the data adequately. Often strong residuals were observed around 0.8 keV (Figure 1). These residuals were interpreted as absorption edges due to highly ionized oxygen OVII/OVIII and so the absorber was called warm or ionized. Theoretically, such absorption features are expected when continuum flux passes through a slab of ionized matter (Halpern, 1982; Reynolds & Fabian 1995). The exact signature of a warm absorber depends upon its column density, shape of the ionizing continuum and ionization state (usually parameterized in terms of ionization parameter which is a dimensionless ratio of photon to electron density). Figure 2 shows the dependence of warm absorber signatures on column density and ionization parameter  $U$ .

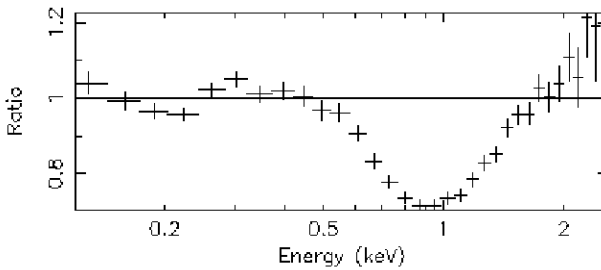


Figure 1: Ratio of ROSAT data of NGC 3516 to a simple power-law model fit. The strong residuals at  $\sim 0.9$  keV are the signature of a warm absorber. (From Mathur *et al.* 1997)

Signatures of ionized gas from nuclear regions of AGNs were known to be present in the UV band as well, from IUE (e.g. Ulrich 1988) and HST (e.g. Bahcall *et al.* 1993) studies. However, the physical properties of the absorber were not known as absorption lines of only a few elements were observed, typically CIV,

NV, Ly  $\alpha$  and in some cases OVI. Quasi-simultaneous observations of quasar 3C351 with ROSAT and HST helped solve the problem. ROSAT data of 3C351 detected absorption edges due to OVII/OVIII and HST observations showed OVI absorption lines. Through detailed photoionization modeling, Mathur *et al.* (1994) showed that both X-ray and UV signatures arise from the same absorbing material.

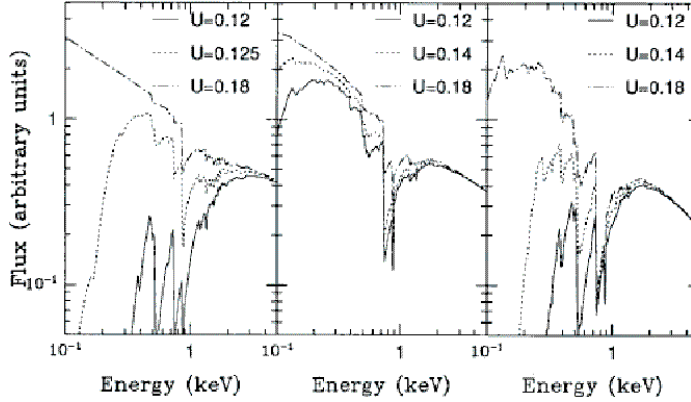


Figure 2: Behavior of a warm absorber with changes in column density  $N_H$ , power-law continuum slope  $\alpha$  and ionization parameter  $U$ . Left:  $\alpha = 0.5$ ,  $N_H = 3.5 \times 10^{22} \text{ cm}^{-2}$ ; Middle:  $\alpha = 0.6$ ,  $N_H = 1.2 \times 10^{22} \text{ cm}^{-2}$ ; Right:  $\alpha = 0.0$ ,  $N_H = 1.2 \times 10^{22} \text{ cm}^{-2}$  (from Fiore *et al.* 1993).

Since the discovery of a unified XUV absorber in 3C351, many observations of many AGNs showed one to one correspondence between absorption in X-rays and in UV (Crenshaw 1997, Monier *et al.* 2001 and references there in). Because the UV and X-ray absorbers were found to be one and the same, constraints from both the datasets could be combined to determine the physical conditions in the absorber (see, e.g. table 3 in Mathur *et al.* 1995). A previously not recognized component of nuclear material was discovered: high column density, highly ionized, outflowing matter situated in or around the broad emission line region. This led to important realization that the mass outflow rate in many cases is comparable to the accretion rate, and that the outflow carries a significant amount of kinetic energy. Understanding of the physical conditions, kinematics and geometry of the absorbing matter led to one of the first comprehensive models of AGN structure (Elvis 2000).

Later observations with ASCA could resolve the OVII edge from OVIII providing better constraints on the physical state of the absorber (George *et al.* 2000). Photoionization models (figure 3) of X/UV absorbers also led to the prediction that in addition to the edges, resonance absorption lines due to highly ionized elements should also be present (Nicastro *et al.* 1999). These could only be observed with high resolution spectroscopy. Complexity, as commonly seen in UV absorption systems is also expected in X-ray warm absorbers (see Mathur 1997 and references there in).

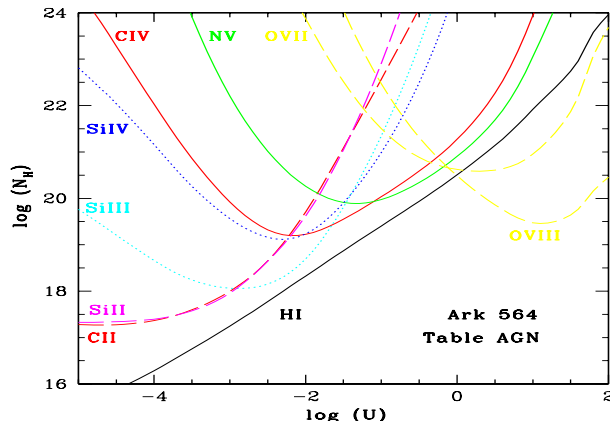


Figure 3: Constraints on parameter space using photoionization models and observed line strengths. Dotted lines correspond to observed values of column density of individual ions; dashed lines mark upper limits and solid lines mark lower limits. The allowed range is then:  $-1.5 < \log U < -1$ , and  $20 < \log N_H < 21.5$  (from Romano *et al.* 2002).

## 2 *Chandra* Observations of Warm Absorbers

High resolution spectroscopy of AGNs known to have warm absorbers, was performed in the first two years of *Chandra*. Here I will discuss only one example and refer readers to Mathur (2001) for a review on *Chandra* results on AGNs.

*NGC 5548*: This well studied AGN was observed with LETG/HRC. Strong, narrow absorption lines from highly ionized species are clearly present in the spectrum (Kaastra *et al.* 2000). The widths of the X-ray lines are consistent with the UV lines. The average blueshift of the X-ray absorption lines was found to be somewhat smaller, but comparable to the UV lines. However, further relation between the X-ray and UV absorbers remained an open issue because of the low S/N and lower resolution of the X-ray spectrum. (The spectral resolution of LETG is  $\sim 300$ – $1000$  compared to  $\sim 10,000$  of HST/STIS in medium resolution.)

The absorption lines/ edges discussed above are observed when there is absorbing gas along the line of sight. The same plasma, when viewed from another angle should exhibit emission lines. In addition to the resonance lines, seen in absorption, forbidden and intercombination lines should also be present in emission (see also Krolik & Kriss 1995). Such emission lines are best studied when the bright nuclear continuum is suppressed. Naturally, the first *Chandra* observations to study emission lines from AGNs were of highly absorbed Seyfert galaxies. Below I review one such example.

*Mrk 3*: *Chandra* HETG/ACIS-S observation of this Seyfert 2 galaxy is reported by Sako *et al.* (2000). A number of lines from a variety of elements were detected in the spectrum. Resonance lines and Fe-L lines, characteristic of photoionized

plasma are strong. The OVII triplet, useful for plasma diagnostics, is also detected. Sako *et al.* conclude that the emission line plasma is clearly photoionized, with practically no contribution from collisionally ionized gas. As such, the plasma characteristics are consistent with a warm absorber seen in emission. All the new observations of warm absorbers have shown consistency with the model predictions based on a common origin of the X-ray and UV absorbing gas.

### 3 UV Studies of Warm Absorbers

UV studies of ionized gas in the nuclear regions of AGNs are done by observing resonance lines of highly ionized ions of mainly CIV and NV, as they were easily accessible first with IUE and then with HST. The higher ionization OVI line was not accessible by these missions for low redshift Seyfert galaxies. OVI observations, however, are very important because together with OVII/OVIII in the X-ray band they offer best constraints on the ionization state of the absorber. This barrier was overcome with the launch of FUSE. Seyfert galaxies known to harbor X-ray warm absorbers indeed showed associated OVI absorption in FUSE spectra (see Kriss 2001). Figure 4 shows FUSE spectrum of a narrow line Seyfert 1 galaxy Akn 564. Strong OVI absorption is clearly present. OVII and OVIII absorption lines are present in the high resolution *Chandra* spectrum (Mastumoto, Leighly & Marshall 2001).

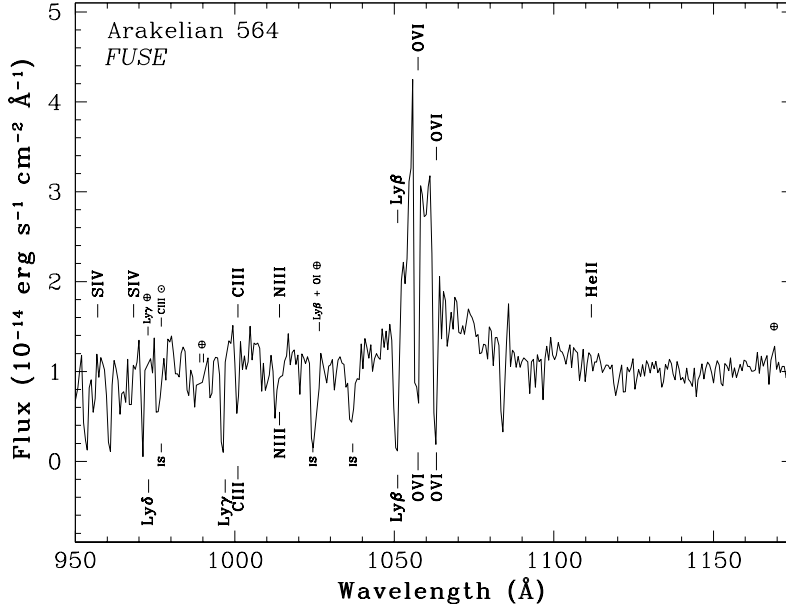


Figure 4: FUSE spectrum of Akn 564 showing strong absorption from OVI and HI Lyman series (from Romano *et al.* 2002).

## 4 Conclusions

High resolution observations of warm absorbers have resulted in beautiful spectra. However, they have not yet given us additional insight into the properties/ kinematics of the absorber. This is because most of the absorption line spectra have low signal to noise ratio (S/N): the measured absorption line equivalent widths are uncertain to  $\pm 40\%$ , larger than those from sensitive ASCA observations. High resolution *Chandra* spectra should be viewed more as a proof of concept than diagnostic tools. Moreover, most of the modeling efforts are preliminary. So interpretations should be made with caution, especially if the results are unexpected. Only when we obtain well constrained parameters can we hope to build and test models of AGN structure and physics. One such effort is lead by Ian George and Mike Crenshaw in obtaining multiwavelength, high S/N spectra of a nearby Seyfert galaxy with a warm absorber. Our team has observed NGC 3783 with HETG/ACIS-S for 900 ksec, with HST/STIS for 34 orbits and also with FUSE and XTE. These observations have resulted in one of the best high resolution spectra of AGNs (figure 5). Modeling efforts are under way (Netzer *et al.*, in preparation). Within next year or so, we will know whether or not our view of the nuclear region of AGNs gets altered dramatically.

Because of space limitations, I could not cover the subject fully. Interested readers are referred to conference proceedings: “Mass Ejection from AGN” and “Mass Outflow in Active Galactic Nuclei: New Perspectives”. I thank the organizers of the meeting for inviting me to give a review talk on warm absorbers in AGNs. This has been a very nice meeting and it is always wonderful to be back home.

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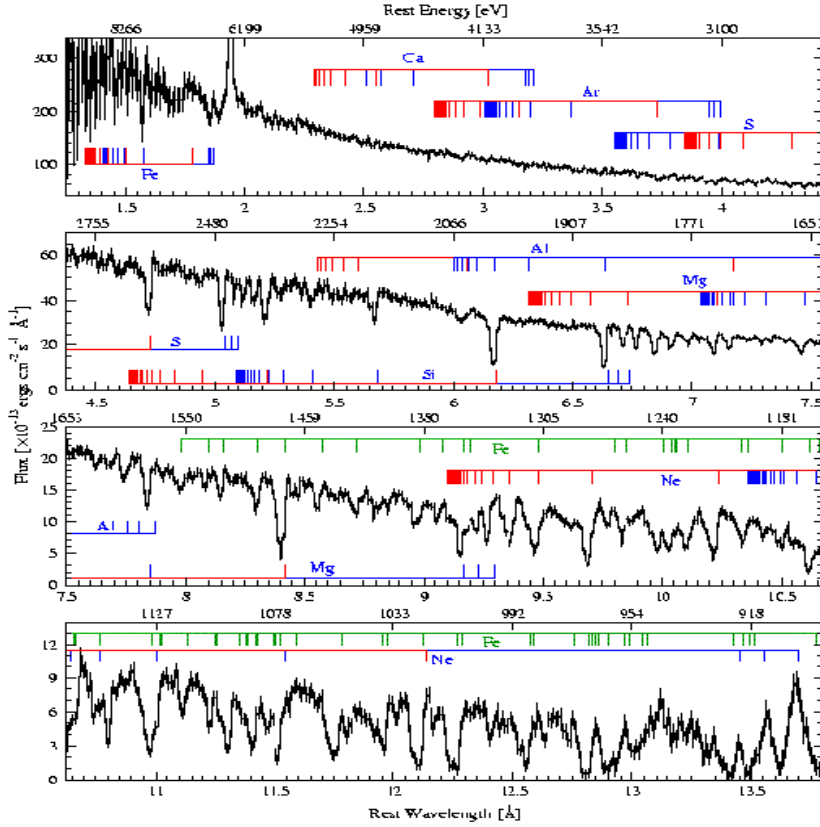


Figure 5: A long look HETG/ACIS-S spectrum of NGC 3783. Note the high S/N in this low wavelength region (From Kaspi *et al.* 2002).

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